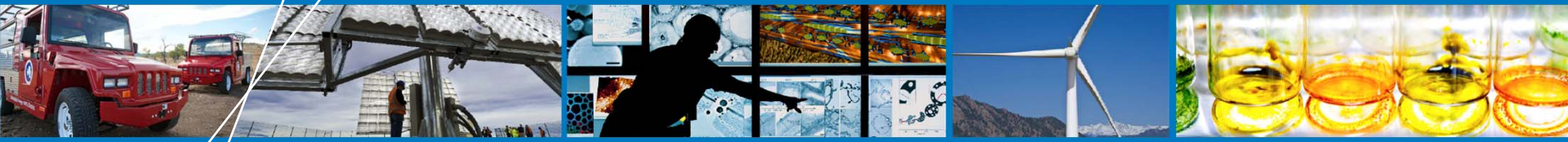
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

What We've Learned from 2.5 Years of Early Market Fuel Cell Operation



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November 6, 2012

NREL/PR-5600-57759

Objectives - Relevance

Assess the technology status in real world operations, establish performance baselines, report on fuel cell and hydrogen technology, and support market growth by evaluating performance relevant to the markets' value proposition.

- **Assess Technology**
  - Independent technology assessment in real world operation conditions
  - Focused on fuel cell system and hydrogen infrastructure: performance, operation, and safety
  - Leverage data processing and analysis capabilities developed under the fuel cell vehicle Learning Demonstration project
  - Material handling equipment, backup power, portable power, and stationary power
- **Support Market Growth**
  - Analyses and results relevant to the markets' value proposition
  - Reporting on technology status to fuel cell and hydrogen communities and other key stakeholders like end users

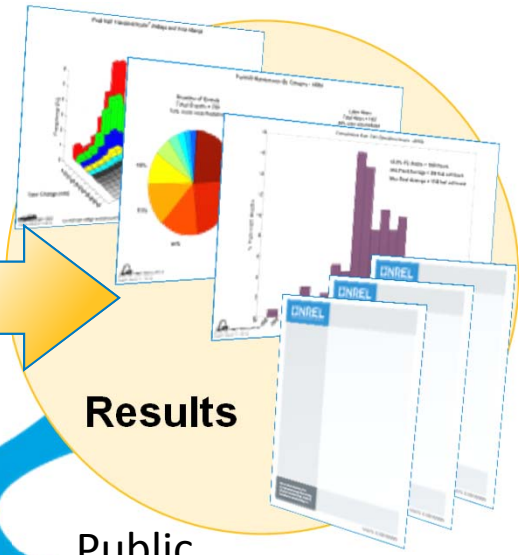
Hydrogen Secure Data Center - Approach

Bundled data (operation & maintenance/safety) delivered to NREL quarterly

Internal analysis completed quarterly

HSDC

NREL's Hydrogen Secure Data Center



DDPs

Confidential

Results

Public

CDPs

Detailed Data Products (DDPs)
- Individual data analyses
- Identify individual contribution to CDPs
- Only shared with partner who supplied data every 6 months[1]

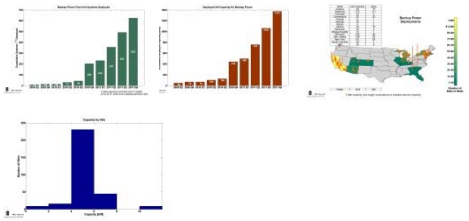
Composite Data Products (CDPs)
- Aggregated data across multiple systems, sites, and teams
- Publish analysis results without revealing proprietary data every 6 months[2]

1) Data exchange may happen more frequently based on data, analysis, and collaboration
2) Results published via NREL Tech Val website, conferences, and reports

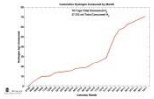
Backup Power CDP Count and Category

BACKUP POWER

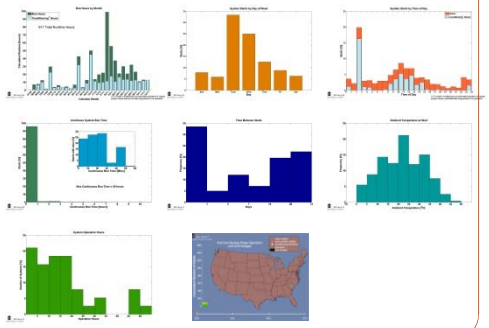
Deployment
(1, 2, 3, 14)



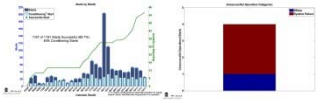
Infra. Operation
(6)



Fuel Cell Operation
(5, 7, 8, 9, 11, 12, 13, 15)

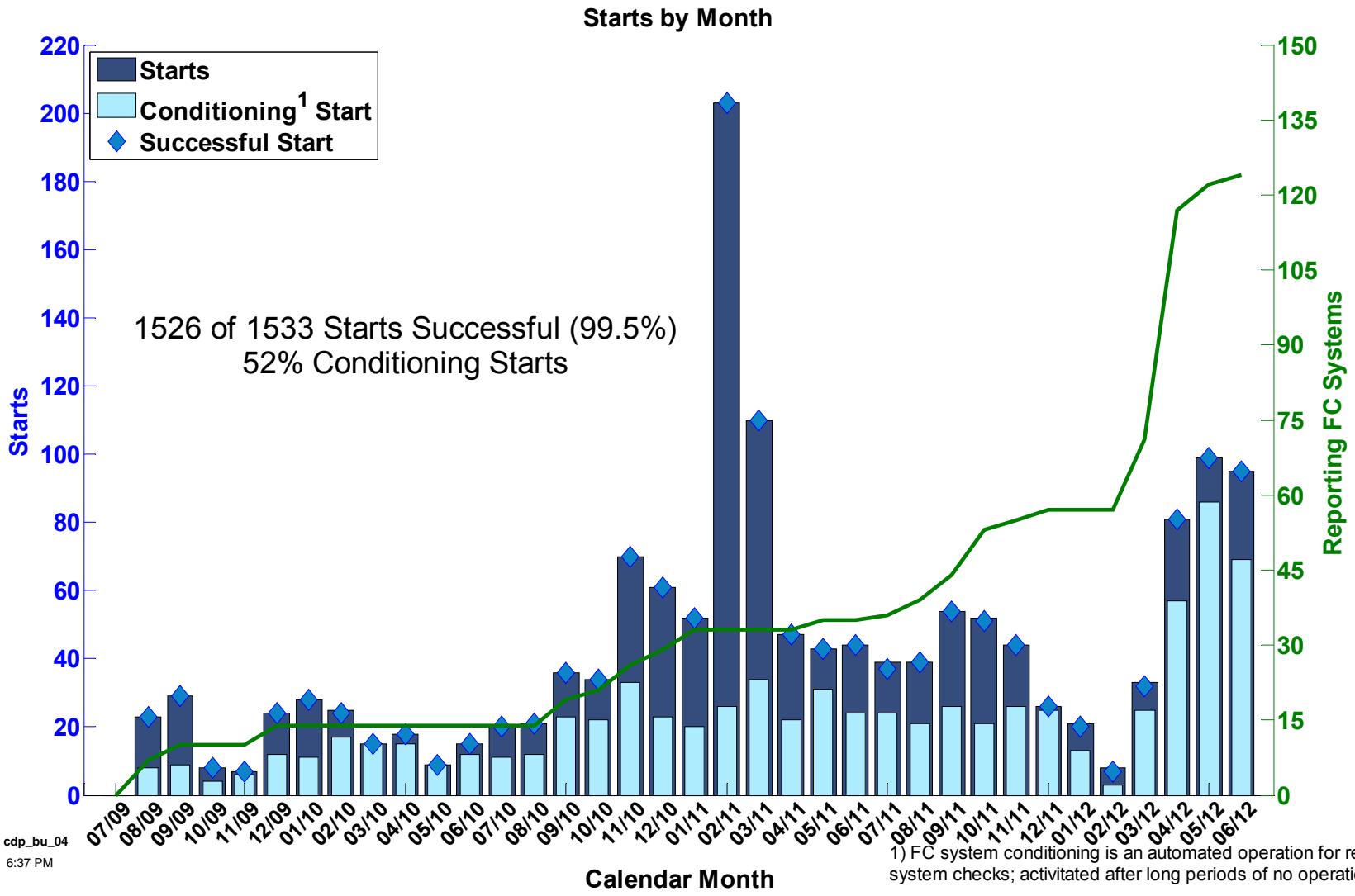


Fuel Cell Reliability
(4, 10)



Reliability: 99.5% Successful Starts

BACKUP POWER



1) FC system conditioning is an automated operation for regular system checks; activitated after long periods of no operation.

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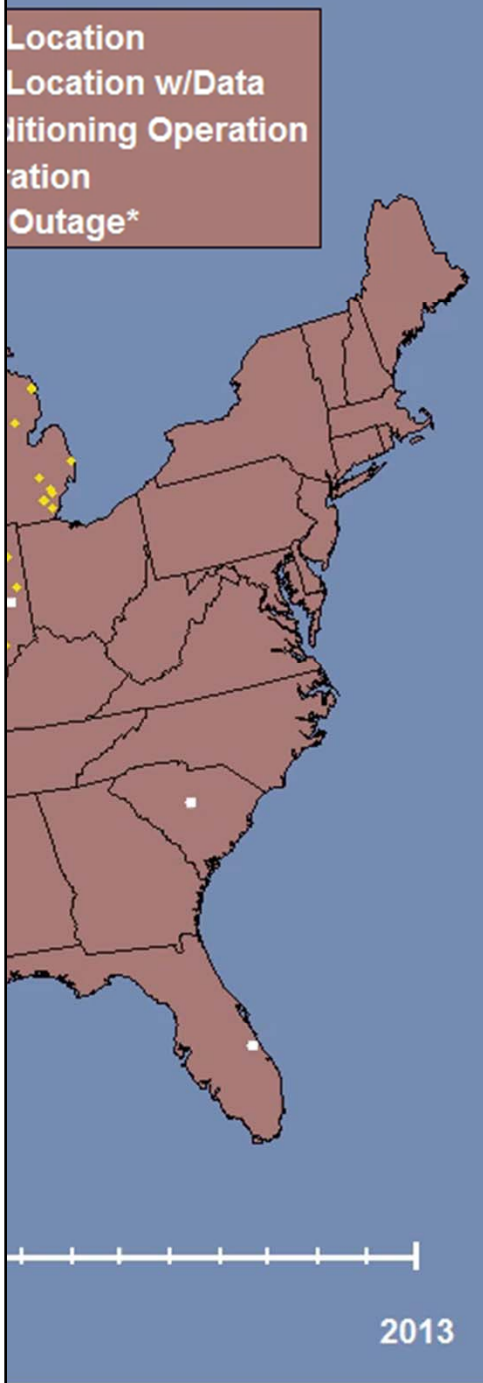
Location
Location w/Data
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Outage*
2013

Cost of Ownership: Backup Power

BACKUP POWER

Gathering data on:

- Site Description
- System Description
- System Requirements
- Capital Cost
- Operating & Maintenance Cost
- Operating Lifetime

for fuel cells, batteries, and generators

	Fuel Cell*	Diesel	Battery
Reliability	+	o	+
Capital Cost ($/kW)	-	+	++
Extended Run Time	++	++	--
Emissions	++	-	++
Noise	+	+	++
Environmental	~	-	~
Weight	+	-	-
Efficiency	+	-	++
Annual Fuel Cost	+	-	++
Annual Maintenance Cost	+	-	++
Maintenance Frequency	++	-	?
Refurbishment	+	+	--
Conditioning Tests	+	-	~
Operation Lifetime	+	++	--

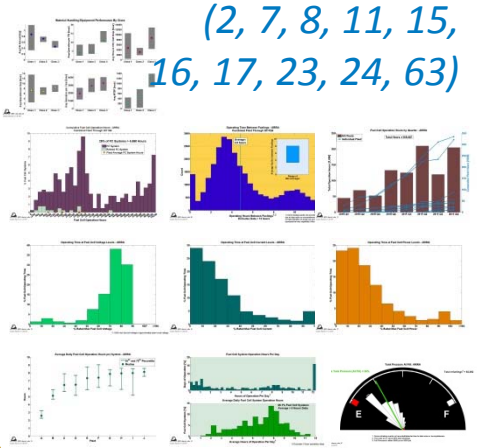
*Tax credit $3,000/kW or 30% total

MHE Result Categories

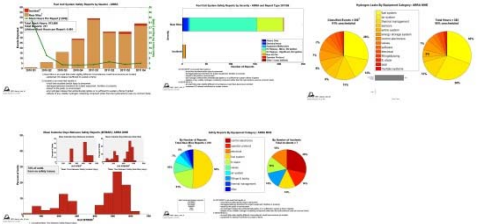
FORKLIFTS

Deployment & Site Overview *(1, 40)*

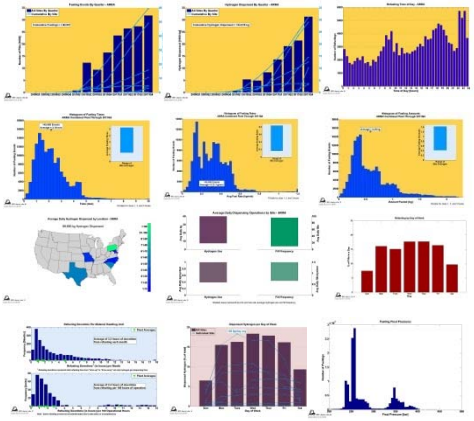
Fuel Cell Operation *(2, 7, 8, 11, 15, 16, 17, 23, 24, 63)*



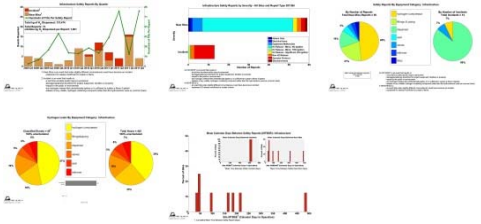
Fuel Cell Safety *(26, 27, 53, 56, 57)*



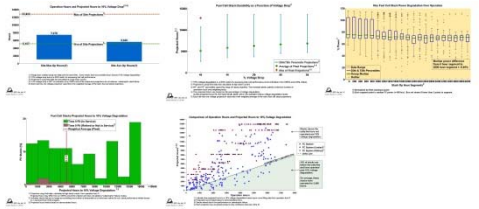
Infra. Operation *(3, 4, 5, 6, 9, 10, 21, 22, 35, 37, 42,62)*



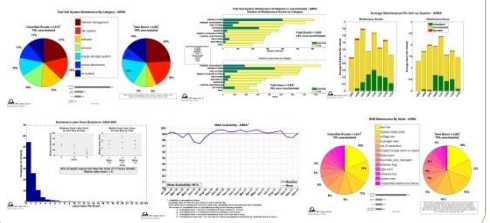
Infra. Safety *(25, 41, 46, 51, 55)*



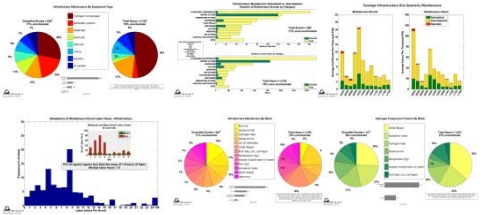
Fuel Cell Durability *(32, 33, 34, 38, 39)*



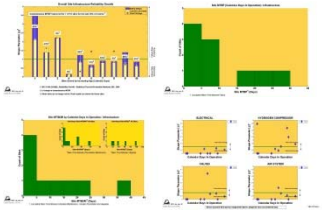
FC Maintenance *(12, 13, 14, 43, 54, 61)*



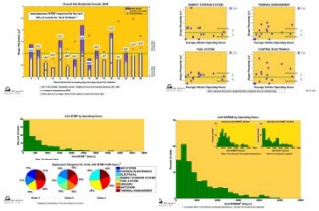
Infra. Maintenance *(18, 19, 20, 44, 47, 52)*



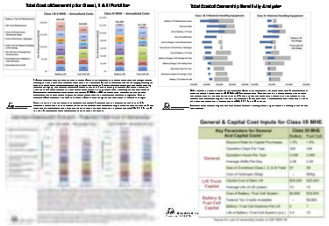
Infra. Reliability *(45, 48, 49, 50)*



Fuel Cell Reliability *(28, 29, 30, 31)*

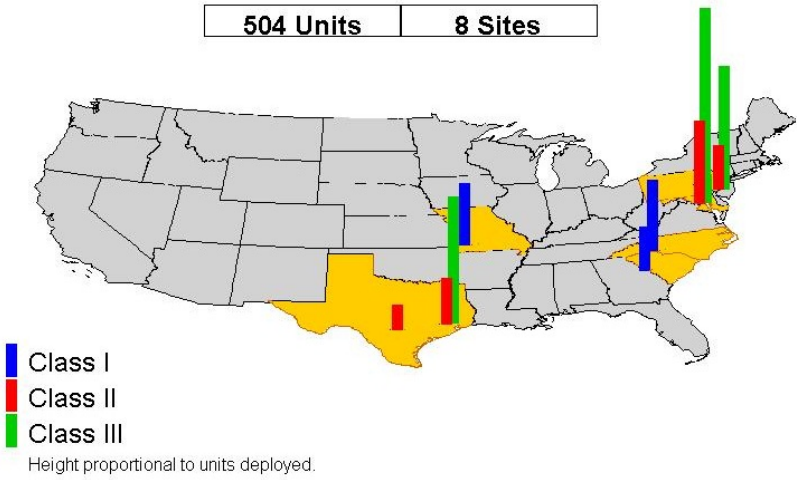


Cost of Ownership *(58, 59, 60,64)*



MHE Operation Status

Key Operation Metric		CDPARRA-MHE-#
Units in Operation (100 Class 1, 62 Class 2, 172 Class 3)	490*	01
Hours Accumulated	1,248,384 hrs*	11
25% of FC Systems	> 5,260 hrs*	02
FC Systems Average > 6 hours Daily	66%*	24
Hydrogen Dispensed	141,500 kg*	04
Hydrogen Fills	197,991*	03
Average Fill Amount	0.6 kg/fill*	10
Average Fill Time	2.3 min/fill*	06
Average Op Time between Fill	4.7 hrs*	08

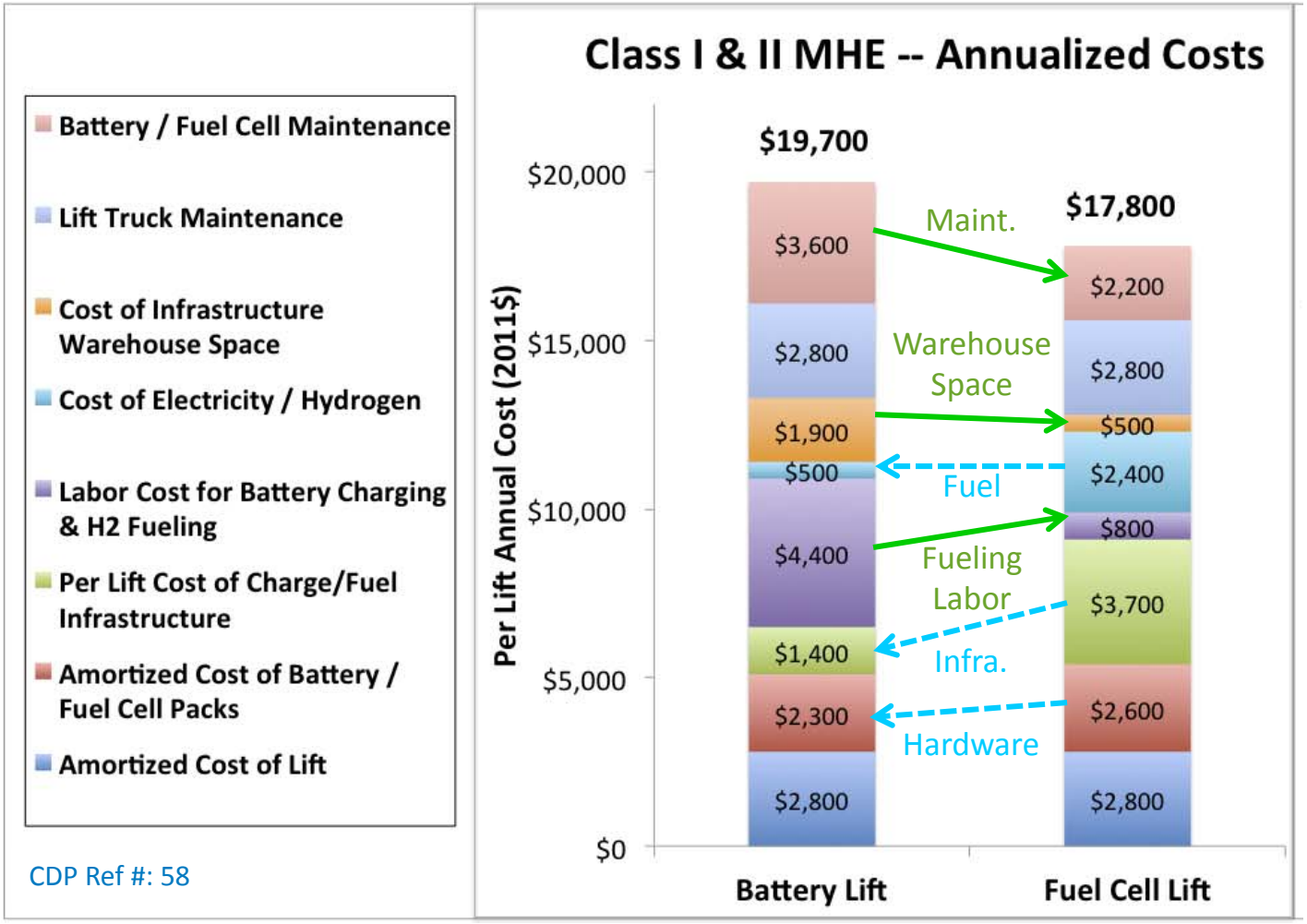


The majority of sites have delivered liquid hydrogen. Two of the eight sites are greenfield sites. Four sites have more than one class of MHE in operation.

*Through June 2012

Annualized Total Cost of Ownership per Unit Identifies Key Cost Advantages are Dependent on Deployment Size

FORKLIFTS



CDP Ref #: 58

Analysis inputs are averages per category, some key inputs are:

- 58 FC lifts
- 333 days per year, 2.5 shifts per day (2,100 pedal hours per year)
- 3 min per hydrogen fill & 10 min per battery change out

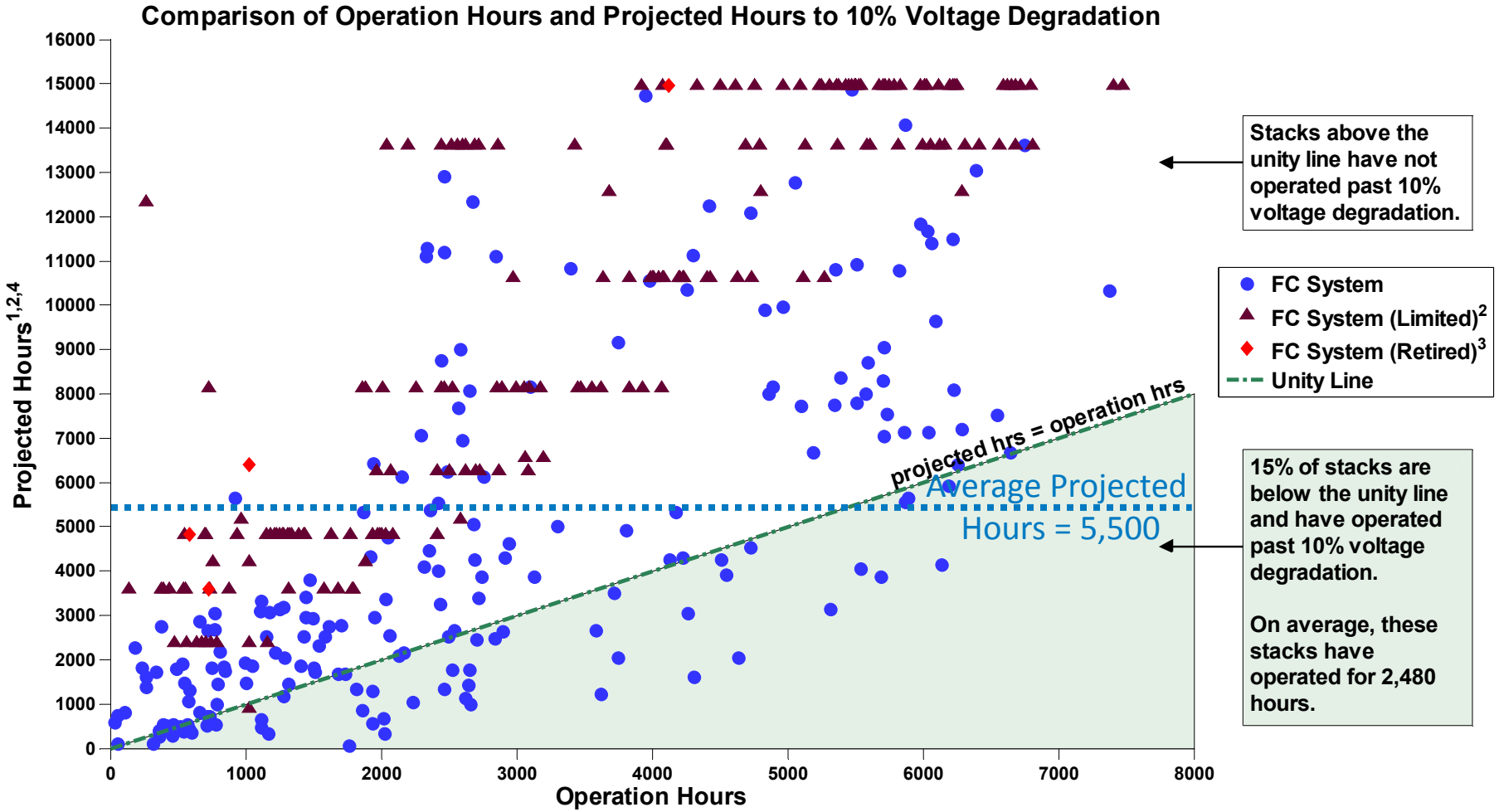
Class III Annualized Cost

- $11,700 FC
- $12,400 Battery

Results assume replacements as needed and do not reflect technology generation improvements or other productivity improvements such as constant power, emissions, and cold environment. FC costs include current tax credit of $3,000/kW or 30% of purchase price. Data source: ARRA and DLA project partner questionnaire and fuel cell performance data.

Durability - Fuel Cell Voltage Degradation

The average projected hours to 10% voltage degradation is 5,500 hours with ~35% of stacks having a projection > 10,500 hours.



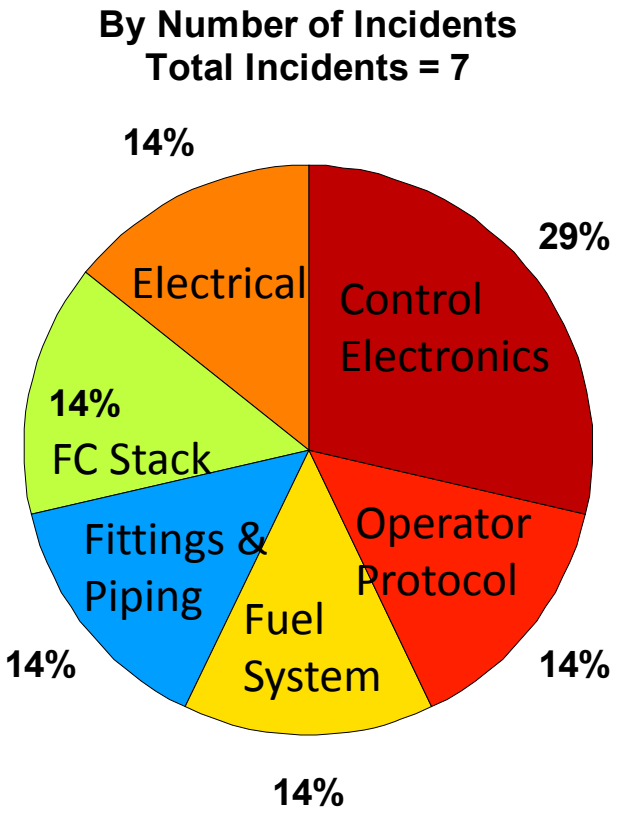
Safety

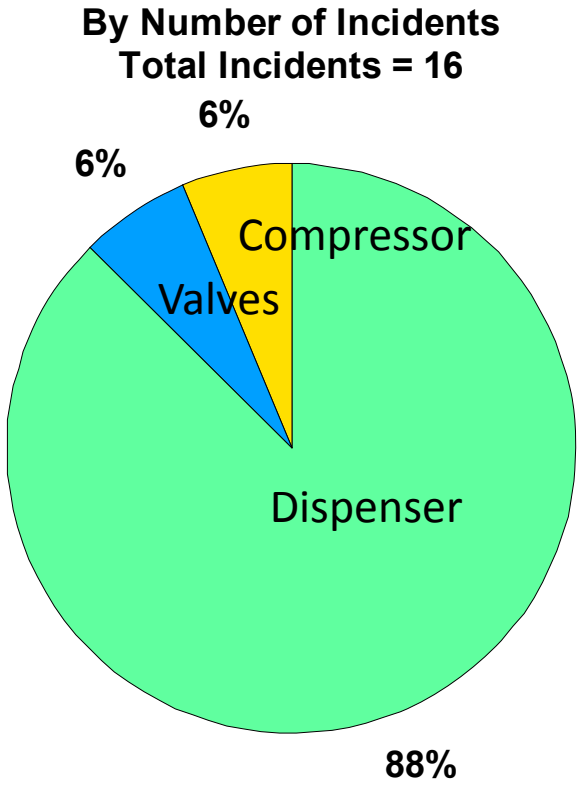
MHE

Majority of safety reports (217) are minor hydrogen leaks (4,480 stack hours per report)

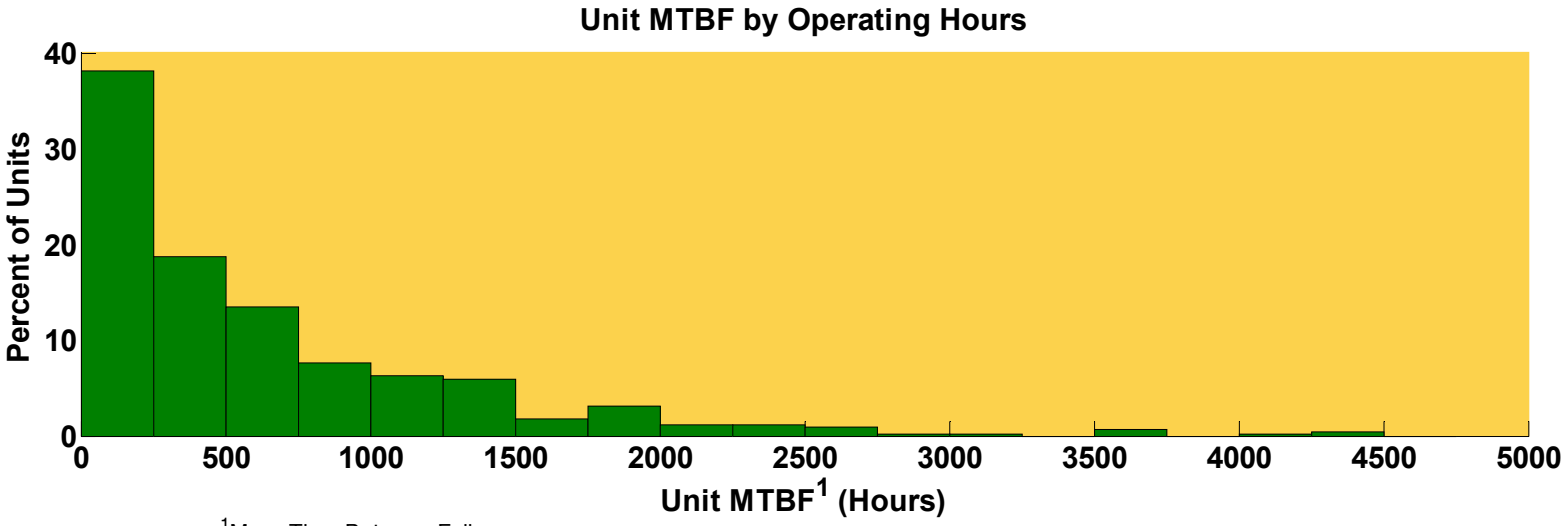
Infrastructure

Majority of safety reports (76) are hydrogen leaks primarily from the hydrogen compressor and plumbing (2,155 kg dispensed per report)

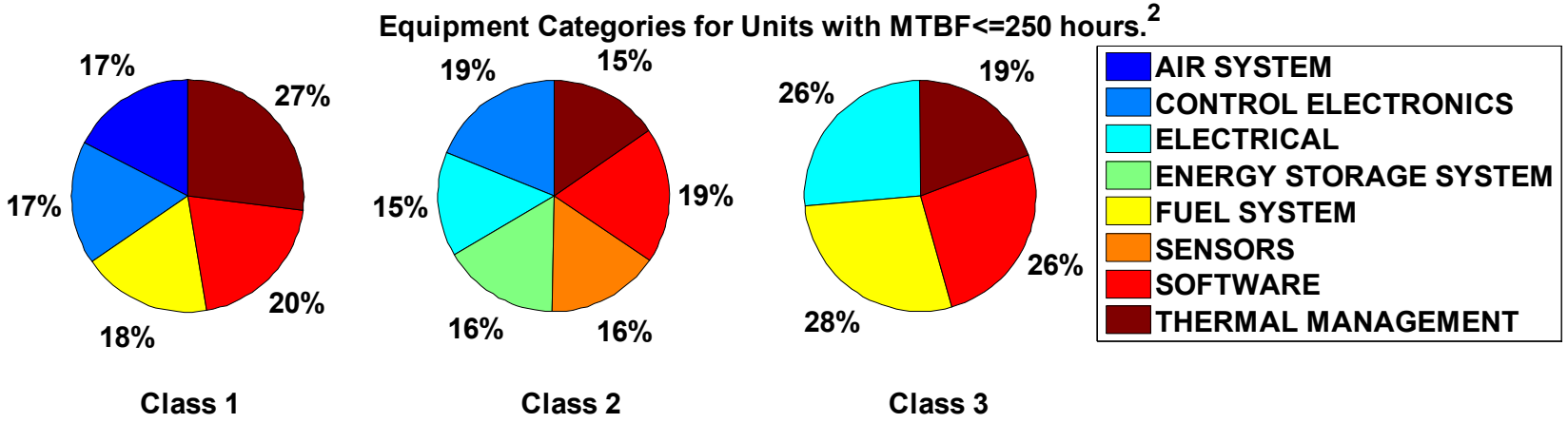




Reliability - Fuel Cell System



[1]Mean Time Between Failure



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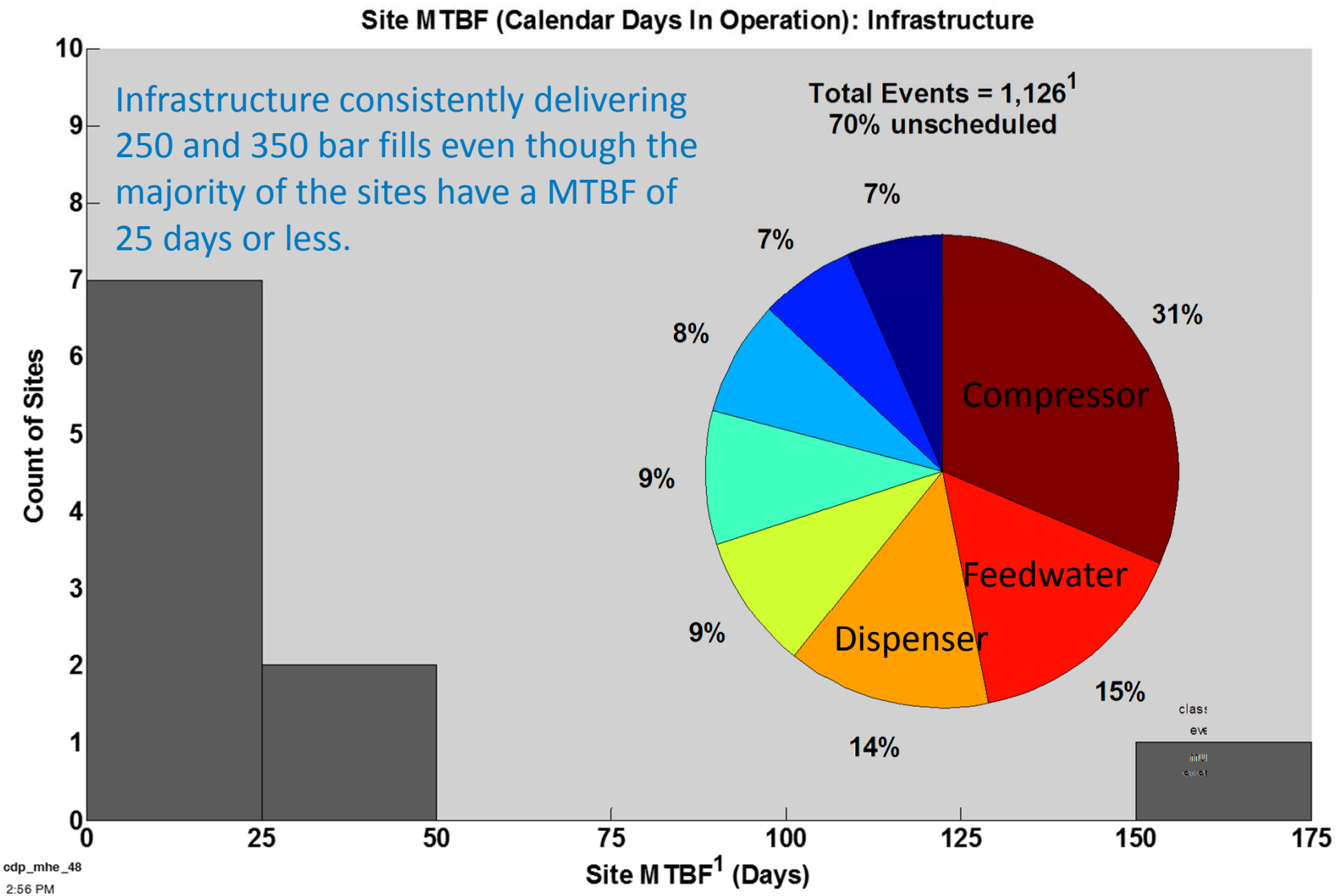
[2] Categories representing <10% of the total are not shown

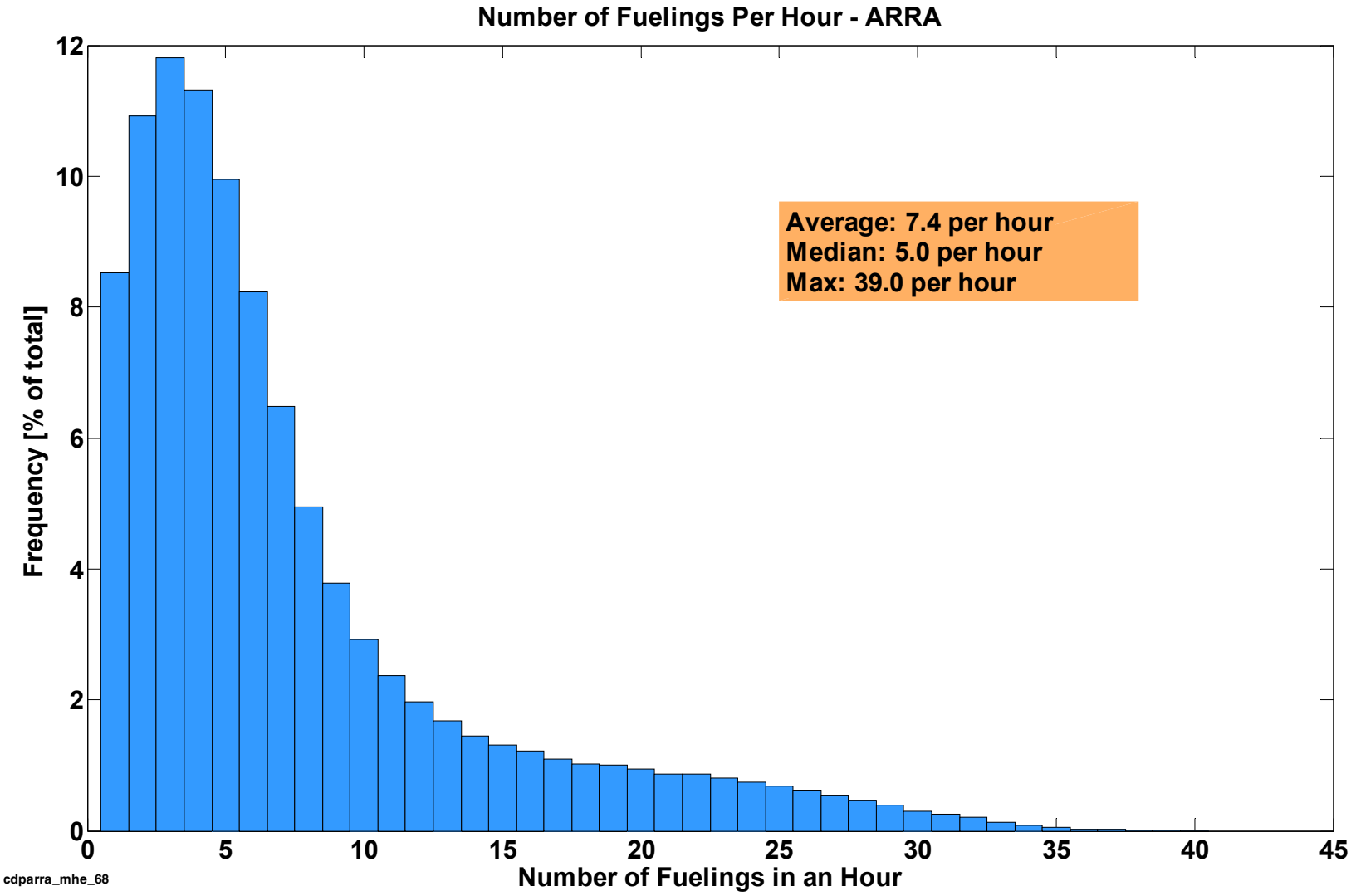
Reliability - Infrastructure



1. Cumulative Mean Time Between Failure

Capabilities - Infrastructure

FORKLIFTS



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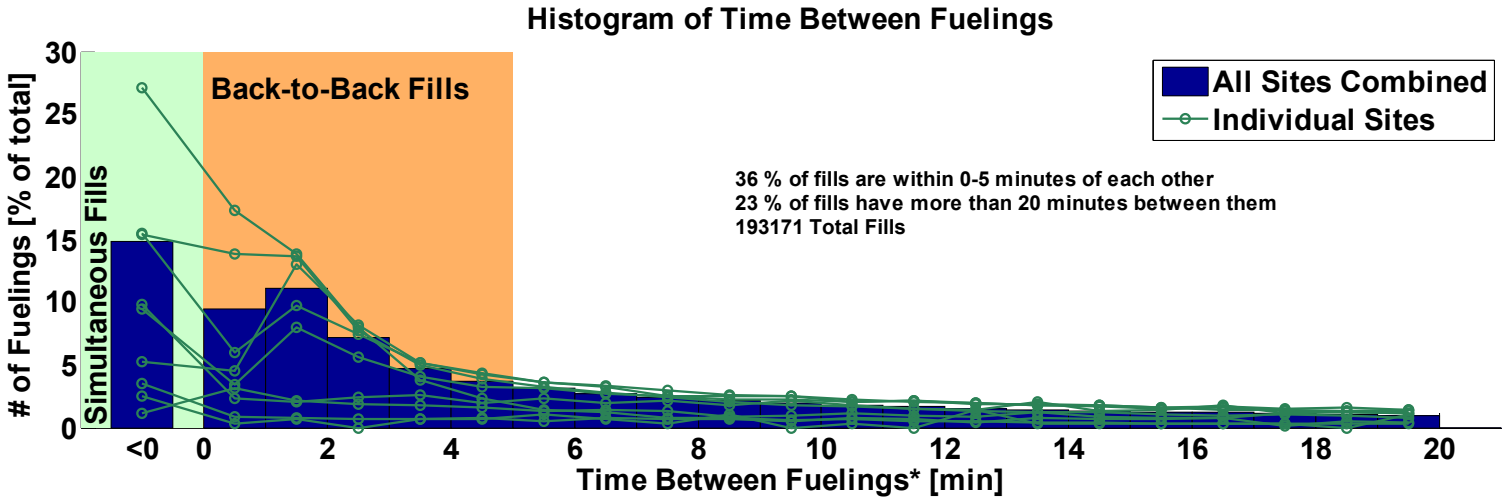
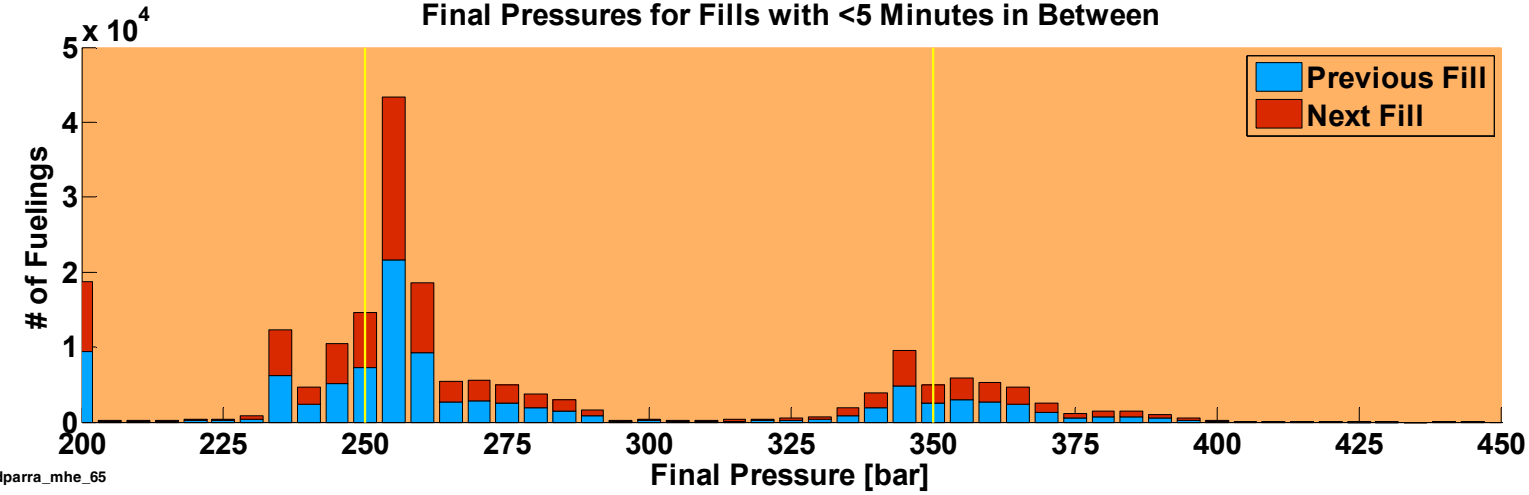
Capabilities - Infrastructure





NREL cdparra_mhe_65

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*Time is from end of fill to start of next fill.

Technical Summary – *What We've Learned*

Fuel Cell Backup Power

- Operating reliability in 15 states with 99.5% successful starts.
- Maximum continuous run time of 29 hours due to an unplanned grid outage.

Fuel Cell Material Handling Equipment

- Operating with an average availability of ~98% at 8 end-user facilities.
- Most systems operate at least 6 hours a day.
- Cost of ownership comparison between fuel cell and battery MHE indicate significant cost savings cost for refueling labor and infrastructure space but much greater cost for hydrogen infrastructure and fuel.

Aggregated data showcases performance over the last two years in MHE and backup power.

Performance results address a need for published results on the technology status.

Data analyses develop as systems operate and based on the key performance areas in the markets.

http://www.nrel.gov/hydrogen/proj_fc_market_demo.html

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Early Fuel Cell Market Demonstrations

Early fuel cell market demonstrations focus primarily on fuel cell backup power and prime power applications as well as material handling equipment (i.e., fuel cell forklifts). Department of Energy-sponsored demonstration projects support fuel cell market transformation activities and help foster the growth of fuel cell markets. In addition, the Department of Defense funds early fuel cell demonstration projects.

NREL receives operational data from these early market fuel cell demonstrations, analyzes, and reports on these data. By aggregating data across numerous industry teams and sites, NREL develops composite data products (CDPs), which provide relevant data results on the technology status and fuel cell performance without revealing proprietary data. These publicly available CDPs help the development community understand the state of fuel cell technologies, identify areas for continued improvement, and provide data metrics that are important to the business case for these fuel cell markets.

Hydrogen PEM fuel cells are leading candidates for use in fuel cell vehicles. Today's commercially available PEM fuel cells are particularly appropriate for low-power applications requiring intermittent backup. Fuel cell backup power systems offer longer continuous runtime and greater durability than traditional batteries in harsh outdoor environments. And with fewer moving parts, fuel cell backup power systems typically require less maintenance than generators or batteries. For specialty vehicles such as forklifts, fuel cells can be a cost-competitive alternative to traditional lead-acid batteries.

Learn More
Subscribe to the biannual Fuel Cell and Hydrogen Technology Validation newsletter, which highlights recent technology validation activities at NREL.

This page provides the following resources:

- Composite Data Products
- Publications
- Presentations Containing All CDPs

Composite Data Products

The public technical analysis results are generated in the form of composite data products. The following CDPs can be sorted by title, category, CDP number, and date updated. Download the CDPs as PowerPoint or JPG files using the links in the two columns on the right. Download the current presentation containing all ARRA CDPs and DLA CDPs or see the archived presentations containing all CDPs.

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